Resonant Frequency of Rotating Anode X-ray Tubes

Innovation/Impact: A hybrid closed bore X-ray Magnetic Resonance (CBXMR) system is facilitated by the development of an MR compatible rotating anode X-ray tube. Unlike an induction motor in a conventional X-ray tube, whose performance degrades in a magnetic field, we propose an X-ray tube design that uses the fringe field of the MR system to drive the motor. One important aspect that must be understood and optimized for this new X-ray tube is its resonance characteristics. A harmonic driving force leads to large wobble at a nearby resonant frequency (RF): an unbounded oscillation in the undamped case and a maximum amplitude in the damped case [1]. This large amplitude vibration of X-ray tubes can cause not only image artifacts due to focal spot movement, but also even mechanical failure. The stabilized CBXMR system will enhance image-guided interventional procedures based on complementary advantages of the two modalities in very close proximity.

Rotating anode X-ray tubes: In the absence of a magnetic field, the conventional X-ray tube motor (Fig. 1 left) can be made out of high strength magnetic or conductive materials; for example, Varian G-1593bi, shows a relatively high RF of the first mode at 72.5 Hz, which is above the operational rotating speed of 60 Hz. On the basis of a 3-phases DC motor, the CBXMR X-ray tube (Fig. 1 right) utilizes a ceramic rotor with windings on it energized in sequence to provide torque. Four bearings are thus needed for three phases and the grounded anode. Nonmagnetic ceramic is used to avoid creating eddy currents in the rotor body that could reduce the angular speed, and so that MR homogeneity is not affected. Structural Instability is increased by the bearing configuration as well as the longer length and the larger ratio of the rotor diameter to the shaft diameter (inducing large weight on the shaft) for generating sufficient torque.

Rotor dynamics FEM modeling: A finite element model (ANSYS, ANSYS, Inc.) of the X-ray tube motors has been developed and validated by experimental data. The model was first verified against factory-provided measurements of a commercial X-ray tube. The resonance of the CBXMR motor is predicted to be about 20 Hz based on the simulation. This RF is indicated by the rotating speed curve where the motor spends more time at resonance, since the larger vibrations reduce the angular acceleration. The results also match well with the peak location at 22.2 Hz of the frequency response measured using a spectrum analyzer (3562A, HP) and an accelerometer (353B34, PCB Piezotronics). The FEM model is currently used to further optimize the CBXMR X-ray tube design to increase the RF above the operating point of 60 Hz.